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Comment on "A New Dark Matter Candidate: Non–thermal Sterile Neutrinos"

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Abstract

I point out that the sterile neutrinos suggested as candidates for "cool" Dark Matter will decay through their mixing with light neutrinos. This leads to an upper bound of about 200 keV on the mass of the sterile neutrinos, but might facilitate their detection.

Recently Shi and Fuller proposed [1] a new kind of Dark Matter candidate: a sterile neutrino, with small but non–vanishing mixing with the ordinary neutrinos. The idea is that a large pre–existing lepton asymmetry stored in light neutrinos can be converted into an asymmetry of massive sterile neutrino through a thermal resonance. Since low–energy neutrinos would be converted first, the resulting relic neutrinos are less energetic ("cooler") than thermal relics of the same mass would be. This mechanism requires [1] a lepton asymmetry $\Delta L \gtrsim 10^{-3}$ and a mixing angle between active and sterile neutrinos $\sin^2 2\theta \gtrsim 10^{-9}$. One then obtains the desired relic density for $m_{\nu_s} \sim 1 \text{ keV} \cdot (0.1/\Delta L)$. An explicit particle physics model along these lines has been constructed by Chun and Kim [2]. Here the sterile "neutrino" is the axino, which mixes with ordinary neutrinos through R–parity violating interactions.

These studies seem to have overlooked the simple fact that the mixing with ordinary, light neutrinos allows the sterile neutrino to decay into three light neutrinos through the exchange of a virtual Z boson. The total decay width of the sterile neutrino is then found to be

$$\Gamma(\nu_s \to 3\nu) = \Gamma(\mu^- \to e^- \nu_\mu \bar{\nu}_e) \cdot \sin^2\theta_{\rm eff} \cdot \left(\frac{m_{\nu_s}}{m_\mu} \right)^5 , \qquad (1)$$

where $\sin^2\theta_{\rm eff} = \sum_{i=1}^3 \sin^2\theta_{\nu_s \nu_i}$. When calculating this decay width one has to keep in mind that two diagrams contribute to the decay into three neutrinos of equal flavor. The corresponding matrix elements are in fact identical to each other, leading to a factor of 2 enhancement of $\Gamma(\nu_s \to \nu_i \nu_i \bar{\nu}_i)$ relative to $\Gamma(\nu_s \to \nu_i \nu_j \bar{\nu}_j)$, $i \neq j$.

From eq.(1) one computes the lifetime

$$\tau_{\nu_s} = 8.5 \cdot 10^6 \text{ yrs} \cdot \frac{1}{\sin^2 \theta_{\text{eff}}} \cdot \left(\frac{10 \text{ keV}}{m_{\nu_s}} \right)^5 . \tag{2}$$

Requiring this lifetime to exceed $2 \cdot 10^{10}$ yrs then leads to the bound

$$\sin^2 \theta_{\text{eff}} < 4.3 \cdot 10^{-4} \left(\frac{10 \text{ keV}}{m_{\nu_s}} \right)^5 , \tag{3}$$

which limits the allowed parameter space of this kind of model. In particular, the lower bound on the mixing angle, which follows from the requirement of adiabatic $\nu_i \rightarrow \nu_s$ conversion, $\sin^2 \theta_{\text{eff}} > 10^{-10}$, implies

$$m_{\nu_s} \leq 200 \text{ keV}. \tag{4}$$

This is well above the range of masses considered in refs.[1, 2]. However, there higher masses were not considered for a purely technical reason: if $m_{\nu_s} \gtrsim 20$ keV, the resonance conversion temperature exceeds the temperature for the QCD phase transition, making the calculation more complicated. The bounds (3) and (4) are independent of this consideration. [In the model of ref.[2] the axino can also decay into a gravitino, but the corresponding partial width is sufficiently small [2].]

The decay of the sterile neutrino into three light, active neutrinos not only leads to a new constraint on the model parameters, it also might allow to detect this kind of "cool" Dark Matter through its decay products. The resulting flux of active neutrinos can be estimated as

$$\Phi(\nu_i) \sim \frac{10^{10} \text{ yrs}}{\tau_{\nu_s}} \cdot \frac{10 \text{ keV}}{m_{\nu_s}} \cdot \Omega_{\nu_s} \cdot \frac{10^{11}}{\text{cm}^2 \sec}. \tag{5}$$

where Ω_{ν_s} is the ν_s relic density in units of the critical density. Detecting this flux will be very difficult, given the low energy of the neutrinos ($E < m_{\nu_s}$). Note also that the flux (5) is smaller than the flux of solar neutrinos, unless τ_{ν_s} is very close to its lower bound. Nevertheless detecting the decay products of ν_s does not appear to be quite as hopeless as the direct detection of these sterile relics.

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References

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[2] E.J. Chun and H.B. Kim, Phys. Rev. **D60**, 095006 (1999), hep–ph/9906392.